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STUDIES OF GLOBAL IONOSPHERIC ELECTRODYNAMICS

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13. ABSTRACT *(Maximum 200 words)*
The distribution of ionospheric plasma in the F layer is intimately related to the electrodynamics of the region. In order to understand many of the morphological features of the plasma, it is necessary to study both the composition and the motion of the plasma both parallel and perpendicular to the magnetic field. At low and middle latitudes we examine various contributions to the electric field, producing plasma motions perpendicular to the magnetic field, and assess their relative importance as functions of latitude and magnetic activity. Understanding the distribution of ion species in the topside equatorial ionosphere also requires consideration of these ion drifts. At higher latitudes, where electric field sources from the inner and outer magnetosphere must be considered, the perpendicular ion drifts can be very large and result in frictional heating of the plasma. This heating produces large scale motion along the magnetic field line that is an inherent part of the plasma circulation in the region. Finally, studies here show that small scale structures in the plasma concentration and electric field at high latitudes are also important in assessing the energy budget and often dominates the electrodynamics of the region.

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STUDIES OF IONOSPHERIC ELECTRODYNAMICS

1. Introduction.

In the F-region ionosphere the transport of plasma perpendicular to the magnetic field is an extremely important factor effecting its composition, temperature and concentration. The electric fields that produce this ExB drift motion of the plasma originate both inside and outside the ionosphere itself. Inside the ionosphere electric field are produced by dynamo action of the neutral atmosphere. Outside the ionosphere, electric fields produced in the plasma sheet, the low-latitude boundary layer and the magnetosheath, are mapped along magnetic fields lines from their source to the ionosphere. The work described here is devoted to a study of these electric fields in an attempt to understand their variability and the effects that this variability can have on the ionospheric plasma itself.

The electric fields that we are studying have an entire spectrum of spatial and temporal scale sizes that behave differently. At large scale sizes, at low and middle latitudes, electric fields map almost unattenuated along magnetic field lines. Studies in this area thus reveal the properties of the source themselves as well as the ionospheric response. At high latitudes even the larger scale electric fields may be associated with significant field-aligned currents. Thus information about the source can be modified. However a characterization of the local field and the response of the ionosphere can be achieved. At small scale sizes, the mapping properties of the field throughout the ionosphere become important and this represents the first level of understanding that must be achieved.

The research activities reported on here, represent some significant advances in understanding the generation and mapping of electric fields in the ionosphere. We have provided descriptions of large scale climatological features of the ionosphere as well as some details of physical processes that are responsible for some of the observed features.

2. The High Latitude Ionosphere.

2.1 Overview

At high latitudes the ionospheric plasma is dominated by ExB drifts that originate in the outer magnetosphere. Here, electric field sources that originate in the magnetosheath and in the low-latitude boundary layer have signatures of ionospheric convection that behave quite differently as the interplanetary magnetic field changes. Interpretation of observations seems to require consideration of both sources but we are unable, at present, to determine the relative importance of these sources in any particular circumstance. Figure 1 summarizes the magnetic field and ionospheric circulation consistent with an electric field originating in the low-latitude

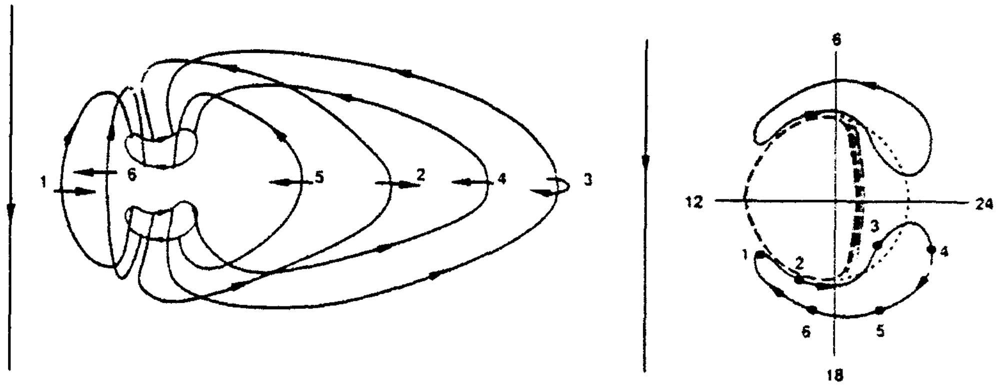

Figure 1: Magnetic field configuration and ionospheric convection pattern for connection to the low-latitude boundary layer.

boundary layer. We note that in this picture a two-cell circulation of plasma in the ionosphere is associated with a similar circulation in the boundary layer and the plasma sheet. Assuming that the frozen in flux concept is enforced everywhere, then all the antisunward flowing magnetic flux in the boundary layer must return sunward in the polar cap. However, violations of this concept would allow this not to be the case but still remain essentially consistent with the indicated ionospheric flow. When the IMF has a southward component the manner in which the geomagnetic field and the IMF are interconnected is quite well understood and the electric field derived from the magnetosheath and transferred to the ionosphere is well specified. Figure 2 shows this interconnection and the resulting circulation of plasma in the plasma sheet, the magnetosheath, and the ionosphere. In this case the frozen in flux concept is clearly violated on the dayside and on the nightside where the ionospheric plasma makes a transition from closed to open field lines and from open to closed field lines respectively. There is thus no requirement for the antisunward and sunward magnetic fluxes to match except in an average sense.

The electric field from the magnetosheath should clearly be dependent on the orientation of the IMF while it is not so obvious that the low-latitude boundary layer flow should have such a sensitivity. Thus examination of how the ionospheric flow changes as the IMF changes can shed some light on the importance of these different sources. A problem in this area is related to defining how the interconnection between the IMF and the geomagnetic field might occur when the IMF is northward. Figure 3 shows one possibility in which interconnection is made on geomagnetic field lines that stretch own the nightside tail of the magnetosphere. In this case the ionospheric plasma stills circulates in a two-cell convection pattern but the sense of circulation is reversed. Studies have shown that sunward flow at very high latitudes is a ubiquitous feature of the ionospheric plasma when the IMF is northward. However, studies also show that a simple

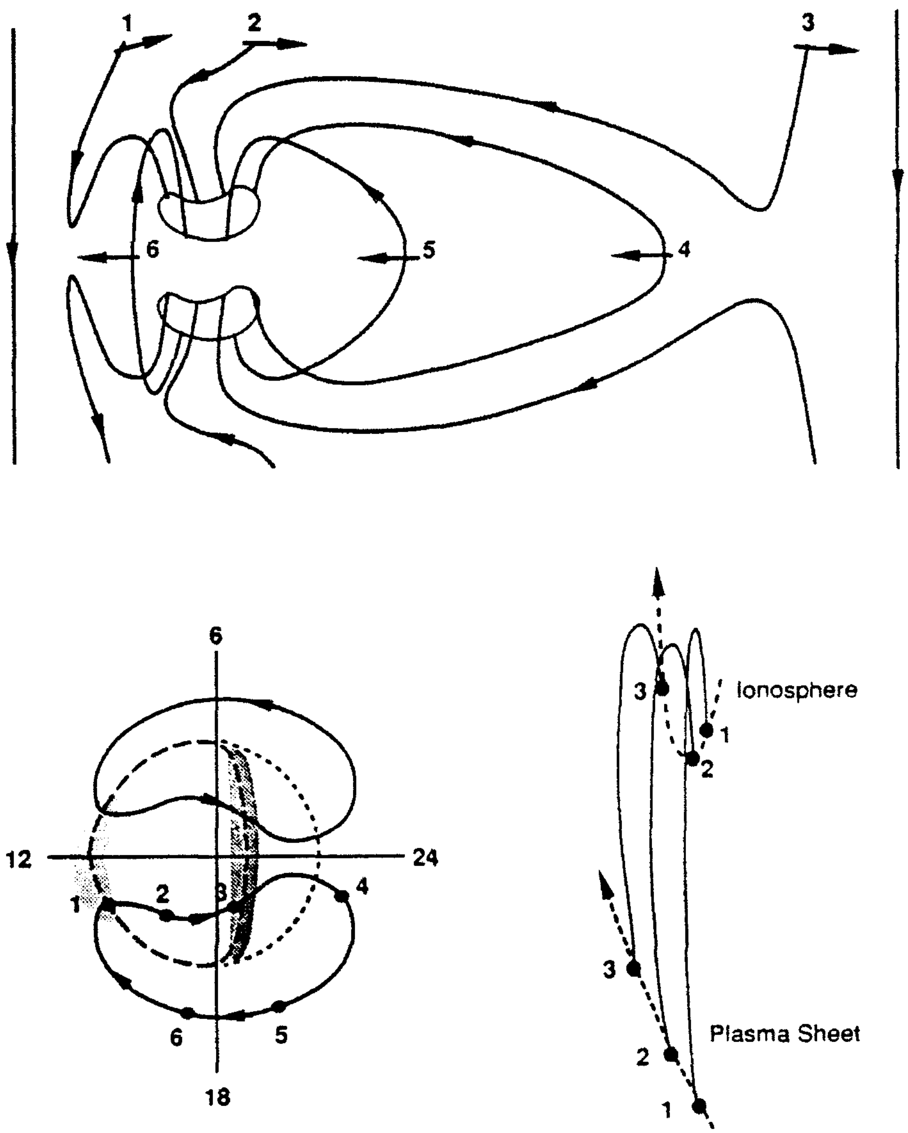

Figure 2: Magnetic field configuration and ionospheric convection pattern for connection to a southward interplanetary magnetic field.

two-cell convection pattern, such as that shown in figure 3, is rarely observed. In fact the most commonly observed feature of the convection pattern can only be explained by including an electric field source from the low-latitude boundary layer. In the most simple of pictures this would lead to a four-cell pattern with the convection cells driven from the boundary layer surrounding, at dawn and dusk, the convection cells from the magnetosheath. However, it is reasonable to also consider the evolution of the pattern as the IMF changes and such considerations lead to the expectation that the ionospheric convection pattern could show considerably more structure than is indicated in figure 3 [Heelis, 1991].

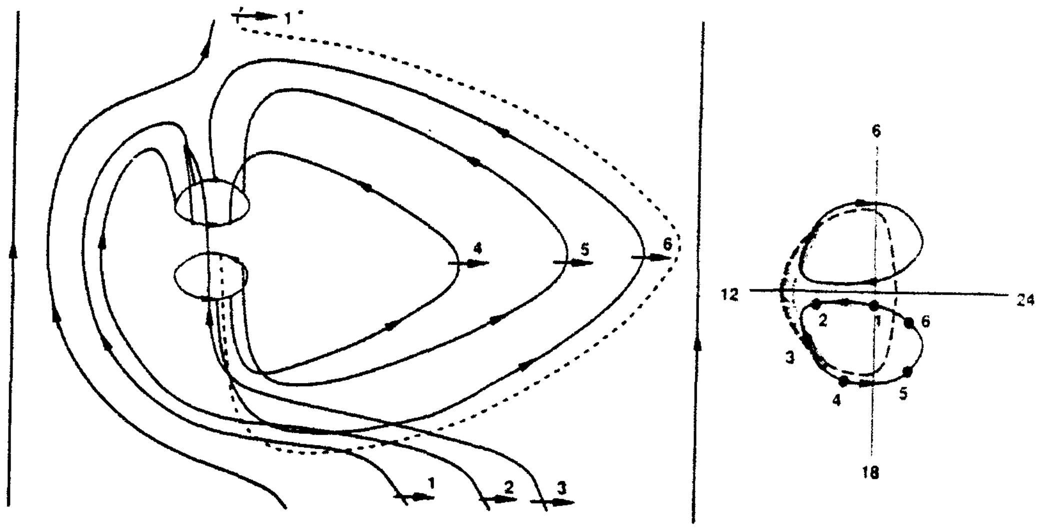

Figure 3: Magnetic field configuration and ionospheric convection pattern for connection to the a northward interplanetary magnetic field.

2.2 Three-Dimensional Considerations.

In addition to the circulation of ionospheric plasma perpendicular to the magnetic field, motions along the magnetic field may also effect the composition and concentration observed at any given location. These field-aligned motions are coupled to the perpendicular motions in two ways. First, the perpendicular motion can transport plasma through regions of ionization production and heating by energetic particles. This leads to plasma expansion above the F-peak. Second, the rapid horizontal motion of the plasma itself can result in frictional heating in the F region and subsequent plasma loss by enhanced chemical recombination. This can lead first to plasma expansion and then to plasma decay. It should be evident therefore that plasma circulation in the F-region is essentially a 3-dimensional concept. As plasma convects through the dayside cusp region it is heated by precipitating electrons, the ionization rate increase due to these same electrons, and the plasma may be frictionally heated by large horizontal drifts. All these processes produce expansion of the plasma as it assumes a new scale height consistent with the heating and production rates. On exiting the cusp region and flowing antisunward, all these processes essentially cease and the plasma relaxes to its former state. In doing so the topside plasma falls to re-establish a smaller scale height. The plasma subsequently flows into the nightside auroral zone where it may again be heated by rapid drifts and energetic particle precipitation.

Figure 4 shows contours of the field-aligned drifts measured by Dynamics Explorer-2 at northern high latitudes in the altitude region between 350 km and 600 km [Heelis et al., 1992].

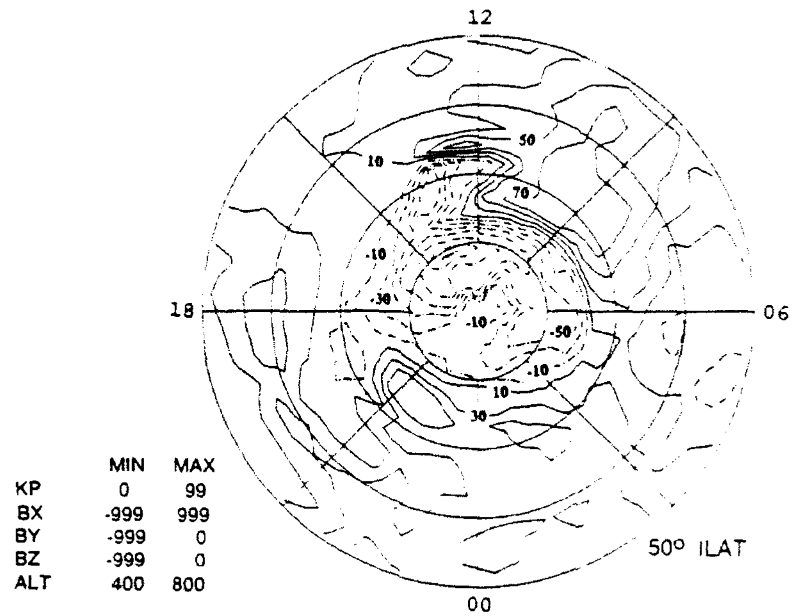

Figure 4: Contours of field-aligned ion drift near 400 km altitude observed by DE-2 in the Northern Hemisphere.

Field-aligned ion drift velocities with average magnitude of about 50 ms^{-1} are seen throughout the high latitude region and transport ion fluxes of 10^{13} $m^{-2}s^{-1}$ both upward and downward along the magnetic field lines. The upward velocities are confined to the auroral zones where frictional heating and heating by low energy electrons is believed to be responsible for the maximum velocities appearing on the dayside and in the cusp region. In the polar cap, where frictional heating is low and energetic electrons are largely absent, the ion drifts are downward. Downward velocities can extend into the nightside auroral zones, but structure in the horizontal ion drift and in the energetic particle precipitation leads to frequent observation of upward drifts at this location. On average the nighttime auroral zone flows are upward with an average magnitude of 30 ms^{-1}. On average a net outward flux is observed to leave the high-latitude ionosphere above 400 km. This outflow of 8×10^{25} s^{-1} is comparable to the energetic ion outflow, apparently of ionospheric origin, observed by DE-1 during the same period. Ionospheric ions move upward as they move sunward in the auroral zones. Some fraction of this upward moving population is apparently energized to escape energy by processes that are not discussed here. They continue to convect antisunward in the polar cap and are seen leaving the

ionosphere by DE-1. The remainder fall in the topside ionosphere as it cools due to the cessation of particle and frictional heating. This cycle then repeats as the antisunward flowing ions return towards the sun in the nightside auroral zone.

2.3 The Mid-Latitude Trough

One region, just outside the main influence of the high-latitude convection pattern is the mid-latitude trough. This region is of particular interest since large fluxes of ions are frequently observed to be moving upward associated with rapid sub-auroral ion drifts (SAID).

This association between the horizontal and field-aligned plasma flows has been used to explain both the plasma features and the dynamics in the mid-latitude trough. Anderson et al. [1991] claim that the large upward velocities sometimes seen in the topside ionosphere of the mid-latitude trough are due to the expansion of the plasma associated with frictional heating. They further claim that this expansion is an important factor in determining the ion concentration that is observed in the trough itself. Calculations by Sellek et al. [1991] have shown that field-aligned flows of the appropriate magnitude can indeed be induced by large horizontal flows. Gombosi and Killeen [1987] have investigated the ability of typical frictional heating rates to provide the O+ plasma with escape energy and more recently Moffett et al. [1992] have described the response of the topside ionosphere to the sudden onset of rapid horizontal drifts exceeding 1 km s^{-1}.

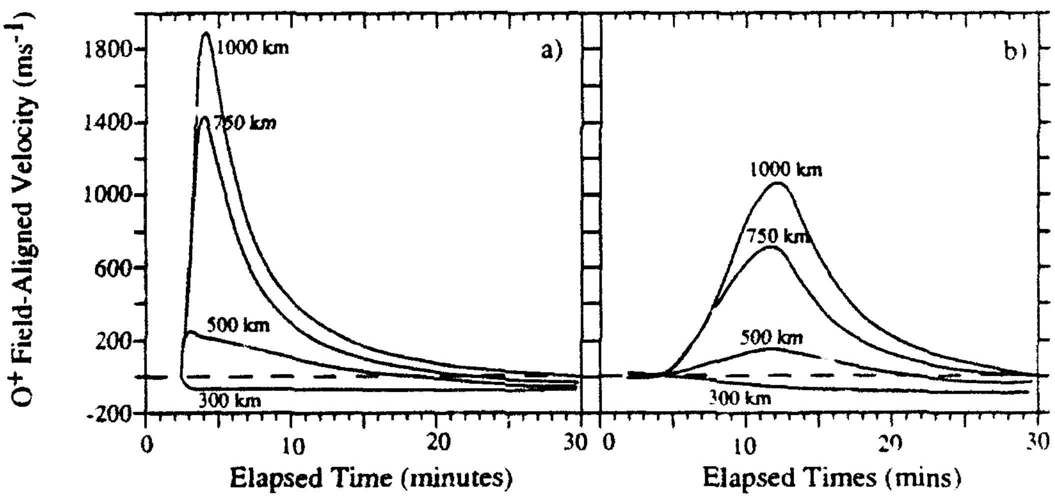

Figure 5: Field-aligned drifts in SAID events of 2 km/s with acceleration times of a) 15 secs and b) 10 mins.

The calculations that we have performed expose the sensitivity of the observed field-aligned ion drifts to the onset time scale of the SAID event itself. Figure 5 shows the field-aligned drifts and

that result when the plasma in the trough region is accelerated to 2 km s^{-1} in 15 seconds and in 10 minutes. The dramatic changes in the maximum field-aligned drift is apparent. Our work suggests that in the presence of a large horizontal ion drift velocity the major factors affecting the energy budget of the plasma can be summarized as follows. In the electron gas collisions with the ions provide a heat source below about 600 km altitude and conduction heats the electrons above this altitude. Above about 1000 km altitude efficient heat conduction in the electrons produces a temperature that is in excess of the ions. Thus ion-electron collisions provide a heat sink for the electrons in this region. In the ion gas below about 700 km altitude, frictional heating of the ions is the dominant heat input and this is countered by collisional cooling to the neutral gas. Above about 800 km advective transport of hot plasma from lower altitudes dominates the temperature increase. This is a transient phenomena that exists while the plasma attains a new scale height. After that the relatively small contributions of heat conduction in the ions and collisional heating and cooling to the electrons determine the time evolution of the ion temperature.

The above discussion highlights three factors that affect the variability in the field-aligned flows. First, the magnitude of the SAID velocity affects the initial magnitude of the plasma pressure gradient formed in the frictional heating region between 400 km and 600 km. Second, the resulting plasma expansion is a transient phenomenon in an F-region flux tube and thus the time of the observation with respect to the onset of the SAID event will effect what part of the transient history is observed. Finally, since the field-aligned flow itself redistributes the heat and changes the field-aligned pressure gradients, the time taken by the plasma to reach the observed SAID velocity is important in determining the maximum field-aligned flows that take place.

Observations of SAID events [Anderson et al., 1991] do not allow a reliable determination of the onset time scale except to establish that it is less than 45 minutes. SAID events can be maintained over time scales of several hours. Even if the onset of the event is instantaneous, the very large peak velocities associated with this short onset time will only be experienced by the plasma already in the SAID location. The onset time for all subsequent plasma will depend upon the convective configuration of the SAID event and not on its initial onset time scale. Observations of the ion drifts associated with a SAID [Spiro et al., 1978] suggest that the plasma enters the westward convection in the SAID region from lower latitudes after flow eastward and poleward. The poleward velocities just equatorward of the SAID are quite small, typically less than 100 m s-1, and even for a SAID half-width of 0.5^{o} (~50 km), it would take ~10 minutes for the maximum SAID velocity to be reached. The evolution of the plasma described in our second scenario is therefore likely to be more representative of observed conditions. In the rest frame of the plasma, the field-aligned drift associated with SAID onset is a transient phenomenon. It

continues only until advection acts to reduce the altitude gradient in the ion temperature which is responsible for a plasma pressure gradient producing the field-aligned drifts. However, observationally the field-aligned drift is not a transient feature. New plasma is continuously convecting into and through the SAID region and thus the transient conditions modeled here will be continuously observed at any fixed location in the SAID region. Observations taken where the plasma enters the SAID region will continuously record peak velocities of the magnitude calculated here. Where the plasma has resided in the SAID region for some time, much smaller velocities will be continuously observed. The peak velocities may be considerably smaller than those shown here. Further calculations in which the time scale for achieving the maximum SAID velocity was 20 minutes show peak field aligned drifts at 750 km altitude of only 400 m s^{-1}.

2.4 Energy Dissipation in Electrodynamic Structures.

Electromagnetic energy is dissipated in the ionosphere in two ways. One as heat and another as momentum in the neutral gas. The heating rate is proportional to the square of the ion-neutral velocity and the Pedersen conductivity while the rate of change of the momentum is linearly proportional to this same velocity difference and the Pedersen conductivity. Thus most of the energy is dissipated as Joule heating. However, when considering the magnitude of this energy dissipation it is important to consider where the heat is dissipated. Since the mapping properties of the electric field that moves the ions are dependent on the scale size of the structure the heating rate is dependent on an effective Pedersen conductivity and not the more commonly used height -integrated quantity [Heelis and Vickrey, 1991]. The scale-size dependent mapping properties of electric fields take into account the attenuation in the electric field along the magnetic field lines. Thus for electric fields that do not map there is dissipation of the electromagnetic energy both parallel and perpendicular to the magnetic

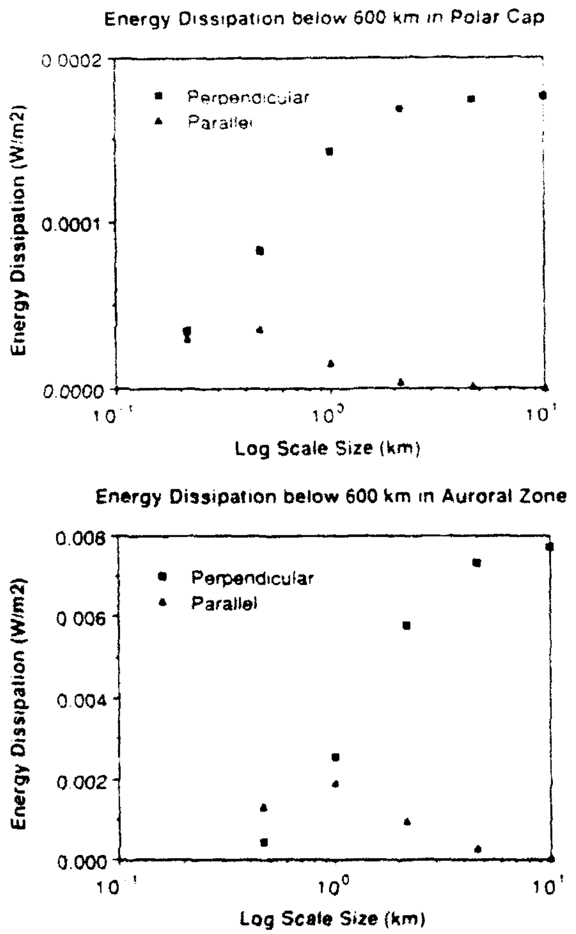

Figure 6: The scale size dependence of energy dissipation from parallel and perpendicular currents in the polar cap and auroral zone.

field lines. The perpendicular dissipation is specified by taking into account the effective flux tube integrated Pedersen conductivity. The parallel dissipation must be accounted for separately. Figure 6 shows the distribution of energy dissipation rates perpendicular and parallel to the magnetic field for a range of different scale sizes and two different ionospheric conductivity distributions describing the polar cap and the auroral zone.

The results demonstrate that an accurate description of the energy dissipation from quasi-static electric fields at high latitudes must include consideration of both the perpendicular and parallel currents. These considerations may be important for perpendicular velocity gradients of 0.5 s^{-1} or greater in the auroral zone. For the simple fixed number density profiles considered here, the parallel and perpendicular electric fields are related through their scale size and the altitude distribution of the Direct and Pedersen conductivities. As one would expect, the largest parallel electric fields occur near 200 km where the Pedersen conductivity has a steep gradient with altitude as does the ratio of Direct to Pedersen conductivity. For sufficiently large field-aligned currents, significant field-aligned potential differences occur above 200 km. Even when these fields are small compared to the ambipolar electric field they can cause about 30% of the energy dissipation to occur from currents parallel to the magnetic field rather than perpendicular to it. The principal significance of this repartitioning of the energy dissipation between perpendicular and parallel current components lies in the difference in altitude where the respective dissipation profiles peak. The perpendicular dissipation dominates at low altitudes where ion-neutral collisions provide the dissipative mechanism, whereas parallel current energy dissipation occurs at higher altitudes through electron-ion collisions. While a quantitative estimate of the total energy dissipated may be obtained by assuming that it all occurs perpendicular to the magnetic field and that the electric field maps unattenuated throughout the ionosphere, it should be emphasized that this is an erroneous description of the physical situation for velocity gradients of the order of 0.5 s^{-1} or greater. Such velocity gradients, associated with large amplitude quasi-static convection electric fields, can be commonplace in the high latitude ionosphere. The simple illustrative calculations performed should be viewed cautiously when the perpendicular ion velocity gradients are very large because the field-aligned electric fields can be large enough that their effect on the ambient plasma distribution should be taken into account.

3. The Low and Middle Latitude Ionospheric Composition

At low and middle latitudes the ionospheric composition and concentration and the ionospheric motion are intimately coupled. The ExB drift motion of the plasma depends dramatically on the distribution of the ionospheric conductivity, but this distribution is itself dependent on the ExB drift motion. In order to unravel some of the complex coupling processes

it is necessary to understand the response of the ionosphere to known ExB drift motions and to understand the circumstances under which these motions change.

A sensitive monitor of the ExB drift motion of the plasma is the height of the peak and the concentration at the peak of the F layer. The behavior of the F-layer peak also effects the distribution of ionospheric species in the topside ionosphere. Knowledge of the topside ionospheric composition can be obtained from satellite data which provide detailed latitude and local time distributions of the ionospheric species at a given altitude. Such a study was undertaken using data from Atmosphere Explorer taken during under solar minimum conditions. Figure 7 shows the average daytime and nighttime distributions of the ionospheric species obtained from this study [Gonzalez et al., 1992]. In the ionosphere H+ is produced primarily by the resonant charge exchange process with O+ and neutral hydrogen. During the daytime this

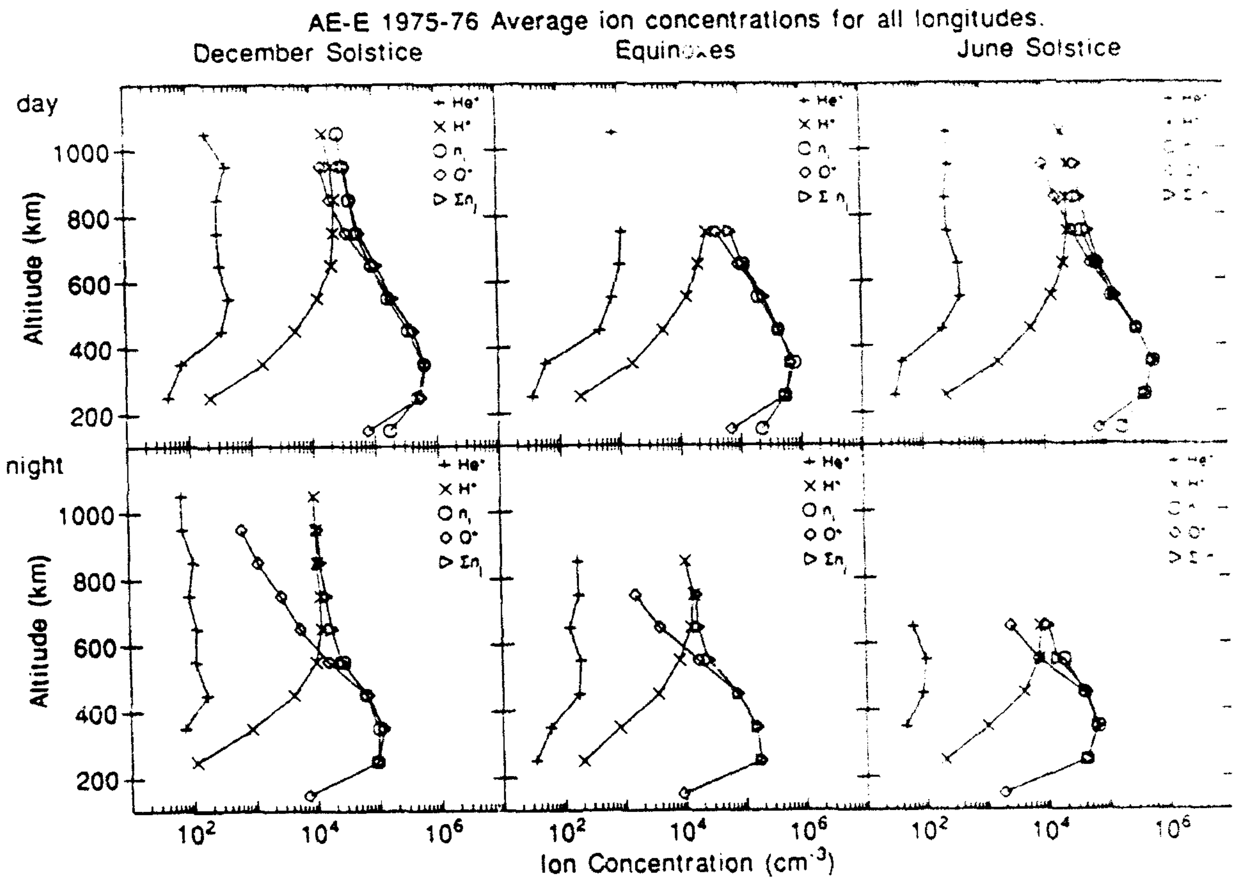

Figure 7: Daytime and Nightime altitude profiles of ionospheric composition obtained by AE-E at different seasons.

process is a sink for O+ in the topside ionosphere and the equilibrium concentrations produce an O+/H+ transition height near the H+ peak. For the solar minimum conditions prevailing during this period the transition height lies between 750 km and 825 km. At night the O+ concentration in the bottomside decays due to recombination. Then the H+ stored in the topside during the days fall to lower altitudes and the charge exchange reaction becomes a source for O+. The transition height is lowered to between 550 and 600 km under these conditions.

The O+ peak concentration changes by about an order of magnitude from day to night, having a daytime value near 106 cm-3. During solar minimum conditions the F-region ExB drifts have almost a sinusoidal local time distribution. The lack of a post-sunset enhancement in the ExB drift means that the average altitude of the daytime and nighttime peak densities are about the same. In this case the peak altitude remains near 350 km. At solar minimum He+ is always a minor ion. The transport of this species will be dominated by the O+ motion and thus a small seasonal variation is seen in this species as well as in the O+.

4. Low and Middle Latitude Electrodynamics

Satellite observations can also be used to study the ExB drift motion of the plasma. Studies of this parameter reveal the dominant local time variations that exist at different latitudes and enable a qualitative determination of the relative importance of different sources for the electric fields. At mid-latitudes the ionospheric plasma drift perpendicular to the magnetic field can be effected by electric fields generated by the dynamo action of the neutral atmosphere in the E region and the F region, and by electric fields generated in the magnetosphere by the interaction of the solar wind with the geomagnetic field. The electric field of magnetospheric origin may manifest itself in two ways that we will term direct electrical influence and mechanical influence. The mechanical influence results from the so-called "disturbance dynamo" [Blanc and Richmond, 1980] produced by frictional and particle heating in the auroral zones. The subsequent motion of the neutral gas is equatorward and westward, by virtue of the angular momentum carried by the gas (i.e. Coriolis force). Depending on the altitude range over which the auroral zone heat source is applied, the disturbance dynamo may exist in the E-region and/or the F-region. In either case the ion drift motion that it produces is predominantly westward at all local times. Calculations by Blanc and Richmond [1980] indicate that a local maximum in the westward ion drift of about 100 ms-1 might be expected between 40o and 50o magnetic latitude but this is evidently dependent on the magnitude and location of the auroral zone heat source that is assumed. The effects of the disturbance dynamo may also be seen for large fractions of a day following substantial auroral zone heating effects associated with magnetic activity. The electrical influence of the magnetosphere solar wind interaction at mid-latitudes can be viewed in

two ways. First, due to inadequate shielding by the currents in the plasma sheet [Jaggi and Wolf, 1973], the electric field may penetrate or leak inside the plasmasphere. Second the plasmasphere itself, which is normally free of large fields from the magnetosphere, may contract to relatively low latitudes during magnetically active times and thus the mid-latitude region may be directly subject to the fringes of the auroral zone electric field. In the latter case we would expect that the local time distribution of the electric field to be similar to that seen in the auroral zone. In the other case the effects of conductivity gradients between the auroral zone and the plasmasphere must be taken into account [Senior and Blanc, 1984a].

The behavior of the mid-latitude ionospheric drift has been extensively studied using ground based radar data from St Santin [Blanc and Amayenc, 1979] and Millstone Hill [Wand and Evans, 1981]. Additional data describing the dynamo fields at mid-latitudes is also available from the Arecibo radar in Puerto Rico [Ganguly, et al., 1987] and the MU radar in Japan [Fukao, et al., 1991; Oliver, et al., 1988].

In addition to observational studies of the mid-latitude drifts, further advances in the determination of magnetospheric fields at mid-latitudes have been made utilizing numerical models with varying degrees of sophistication. These models [Spiro and Wolf, 1984; Senior and Blanc, 1984b)] show that the penetration of the magnetospheric field equatorward of the auroral zone results in a different local time distribution of the east-west drift than would be found in the auroral zone itself. A study by Blanc [1983] suggests that penetration fields and disturbance dynamo fields may both contribute to the observed drift signatures and that careful evaluation of the local time effects of each is necessary to separate them.

This work was devoted to describing the latitudinal and local time distributions of the east west drift observed by DE 2 equatorward of the auroral zone . By examining the distributions during quiet and disturbed times and contrasting them with the findings of other observational and theoretical studies we are able to assess the influence of solar dynamo fields and electric fields from magnetospheric sources. Figure 8 provides the comparison of data from various sources including that generated by this work [Heelis and Coley, 1992].

We have examined the zonal ion drifts observed by DE 2 during magnetically quiet and disturbed periods defined by levels of Kp. It is evident that division of the data using this parameter does not include or exclude magnetospheric effects from a particular latitude. Rather the magnetospheric effects are modulated by this division. Determination of the local time distribution of zonal ion drifts from DE 2 necessarily mixes season and local time. Despite these limitations there are many areas of agreement between the features observed in this data and those described in data obtained from ground based radars.

It is apparent that explanation of the observed features in the local time and latitude variations in the zonal ion drifts seen by DE 2 requires both tidal motion of the neutral

atmosphere and magnetospheric sources to be included at different locations and under different conditions. In considering magnetospheric sources, three local time distributions associated with

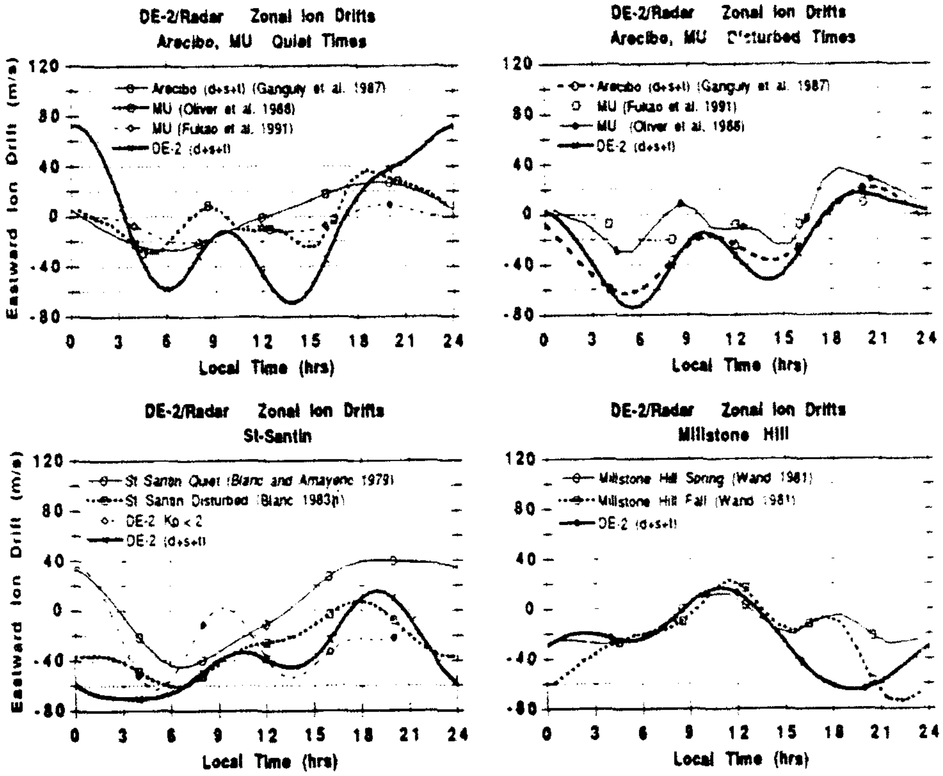

Figure 8: The local time distribution of zonal ion drifts observed by DE-2 *and different ground stations.*

the auroral zone field itself, penetration of the field equatorward of the auroral zone and the magnetospheric disturbance dynamo must all be accounted for. These latter two sources are not just present during disturbed times and dominate the local time distribution at latitudes between 45° and 55° even during quiet times as defined here by Kp ≤ 2. At latitudes above 50°, during disturbed times defined by Kp ≥ 3, the expansion of the auroral zone can directly influence the zonal ion drift observed.

The influences of the electric field sources can be summarized as follows.

1. Semidiurnal and terdiurnal tides are most important during quiet times between 25° and 55° magnetic local time.

2. The influence of the disturbance dynamo and magnetospheric penetration field are seen on average down to 45° during quiet times and down to 35° during disturbed times.

3. Direct influence of the auroral zone electric field is important on average down to 60° during quiet times and down to 50° during disturbed times.

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5. Publications

The previously described work has provided the opportunity to both advance our understanding of the dynamic ionosphere and to distribute our findings to the community. This report attempts to summarize the work that has been lead by scientists at the University of Texas at Dallas. In addition a number of collaborative efforts have been undertaken with significant progress. In all 9 publications have appeared or will appear from these efforts. The following pages contain the abstracts of these papers all of which contain more detailed information on the topics discussed.

Anderson, P. C., W. B. Hanson, and R. A. Heelis, The Ionospheric Signatures of rapid sub-auroral ion drifts, *J. Geophys. Res*, **96**, 5785-5792, 1991.

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The Ionospheric Signatures of Rapid Subauroral Ion Drifts

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Subauroral ion drifts (SAID) are latitudinally narrow regions of rapid westward ion drift located in the evening sector and centered on the equatorward edge of the diffuse aurora. Observations of SAID as identified by the ion drift meters on the Atmosphere Explorer C and Dynamics Explorer B spacecraft are utilized to determine their effect on the *F* region ion composition, their relationship to the mid-latitude trough, and their temporal evolution. At altitudes near the *F* peak a deep ionization trough is formed in regions of large ion drift where the O^+ concentration is considerably depleted and the NO^+ concentration is enhanced, while at higher altitudes the trough signature is considerably mitigated or even absent. SAID have been observed to last longer than 30 min but less than 3 hours, and their latitudinal width often becomes narrower as time progresses. The plasma flows westward equatorward of the SAID and becomes more westward as invariant latitude increases. Poleward of the SAID, the flow is, on average, westward throughout the auroral zone in the evening, while near midnight it becomes eastward.

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 97, NO. A4, PAGES 4299–4303, APRIL 1, 1992

Ion Composition of the Topside Equatorial Ionosphere During Solar Minimum

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We have used observations from both the Bennett ion mass spectrometer and the retarding potential analyzer on board the Atmosphere Explorer E satellite to study the longitudinally averaged O^+, H^+, and He^+ concentrations from 150 to 1100 km in the equatorial ionosphere during the 1975-1976 solar minimum. Our results suggest that the ion mass spectrometer measurements need to be increased by a factor of 2.15 to agree with the densities from the retarding potential analyzer and with ground-based measurements. The peak H^+ concentrations are about 2.5×10^4 cm^{-3} during the day and 10^4 cm^{-3} at night and vary little with season. The O^+/H^+ transition altitude lies between 750 and 825 km during the day and between 550 and 600 km at night. He^+ is a minor species at all altitudes; its concentration is highly variable with a maximum value of about 10^3 cm^{-3} during equinox daytime.

J. Geomag. Geoelectr., 43, Suppl., 245-257, 1991

The High Latitude Ionospheric Convection Pattern

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Simple examination of models of the magnetic and electric field indicate that both direct connection with the interplanetary field and connection to the low-latitude boundary layer flow are required to explain many of the repeatable features in the observations of high latitude ionospheric motions. During times of southward IMF, these two sources of the electric field may not be easily discernible and during time of northward IMF the details of the magnetic field geometry are important in determining the geometry of the ionospheric convection cells. When both these sources of the electric field are considered, a transition from southward to northward IMF leads to distorted two-cell convection patterns that can contain multiple cell configurations.

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East-West Ion Drifts at Mid-Latitudes Observed by Dynamics Explorer 2

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Zonal ion drifts measured from the the polar orbiting DE 2 spacecraft are examined to determine the effects of dynamo electric fields and penetration of high latitude electric fields at middle latitudes. Construction of a local time distribution from satellite data results in a mixture of local time and season as well as a range of magnetic activity encompassing $Kp \leq 2$ and $Kp \geq 3$. Thus some combination of magnetospheric effects, expected to dominate during disturbed times, are seen during both quiet and disturbed times and solar tidal influences are most easily observed during quiet times. During quiet times, at invariant latitudes near 25°, the solar diurnal tide dominates the local time distribution of the ion drift. At latitudes above 50° a diurnal component of comparable magnitude is also present, but its magnetospheric origin produces a shift in phase of almost 180° from the lower latitude diurnal tide. In the intervening region, between 20° and 50° invariant latitude, semidiurnal and terdiurnal components in the local time distribution of the drift velocity are also seen. These components are generally larger than those seen by ground based radars during quiet times and may be attributable in part to a difference in solar activity and in part to a combination of the solar tides and magnetospheric penetration fields.

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Three-Dimensional Ionospheric Plasma Circulation

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Examination of the ion drift velocity vector measured on the DE 2 spacecraft reveals the significance of ionospheric flows both perpendicular and parallel to the magnetic field at high latitudes. During periods of southward directed interplanetary magnetic field the familiar two-cell convection pattern perpendicular to the magnetic field is associated with field-aligned motion predominantly upward in the dayside auroral zone and cusp, and predominantly downward in the polar cap. Frictional heating by convection through the neutral gas and heating by energetic particle precipitation are believed to be responsible for the bulk of the upward flow with downward flows resulting from subsequent cooling of the plasma. Some of the upward flowing plasma is apparently given escape energy at altitudes above about 800 km. The average flow of ions across the entire high-latitude region at 400 km is outward and comparable to the energetic ion outflow observed at much higher altitudes by DE 1.

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Energy Dissipation in Structured Electrodynamic Environments

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The coupling of electromagnetic energy into the ionosphere and thermosphere is an essential consideration for understanding the thermal structure and dynamics of the neutral and charged particles at high latitudes. Often the dissipated electromagnetic energy exceeds that deposited by precipitating energetic particles at high latitudes. It is usually assumed that the profile of the ion Pedersen conductivity determines the altitude dependence of the energy dissipation rate. Herein we point out the strong altitude dependence of the energy dissipation rate on the spatial scale sise of the imposed electric field. To illustrate the importance of such considerations, we show examples of the ubiquity of electric field structure in the high-latitude ionosphere; this is particularly prominent when the interplanetary magnetic field has a northward component. We then show quantitatively how the existence of electric field structure with scale sises of 10 km or less strongly impacts both the altitude extent over which the electromagnetic energy is dissipated and its partitioning between current systems perpendicular and parallel to the magnetic field.

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Upflowing Ionospheric Ions in the Auroral Region

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Observations of upflowing ionospheric ions are obtained nearly simultaneously by DE 1 and DE 2 over the nightside auroral regions. At low altitudes, the mean value of the net upward ion number flux is of the order of 10^9 cm^{-2} s^{-1}. The ionosphere is predominantly O^+, and the flux of ions with energy greater than 5 eV is a very small fraction (less than 1%) of the total ion flux. At high altitudes, the upflowing ions are accelerated by a parallel electric field and heated (with characteristic energies of hundreds of electron volts). Comparing upflowing fluxes at high and low altitudes yields an estimated height of the bottom of the auroral acceleration region of 1400-1700 km for the region of peak potential drop. This low-altitude acceleration could either be from a parallel electric field or from perpendicular acceleration. The fluxes at the edges of the arc are mostly H^+ thus implying a higher-altitude base of the acceleration region at the edges where the potential drop is lower.

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 96, NO. A10, PAGES 17,847–17,863, OCTOBER 1, 1991

Coordinated Radar and Optical Measurements of Stable Auroral Arcs at the Polar Cap Boundary

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A specialized incoherent scatter radar scanning mode has been developed for use in conjunction with simultaneous real-time all-sky images. These complementary diagnostics are used to examine the aeronomy and electrodynamics of stable auroral arcs that delineate the boundary between the polar cap and the auroral oval. The first arc discussed, observed at 2000 MLT, represents the boundary between antisunward plasma flow in the polar cap and sunward return flow equatorward of the arc. The arc defined an equipotential in the high-latitude convection pattern in that no plasma flowed across the arc. The radar line-of-sight velocity measurements also indicate that this arc is consistent with a convergent electric field and an associated weak upward field-aligned current. The second arc was observed at 2330 MLT and was associated with a nightside gap or magnetic reconnection region. Strong antisunward flow was observed directly across the arc, although a velocity shear was superposed on this steady flow along the poleward edge of the arc. Detailed plasma density, temperature, and line-of-sight velocity measurements from the radar are presented for both arcs to define the electric field, horizontal and field-aligned currents, and thermal plasma parameters associated with these arcs.